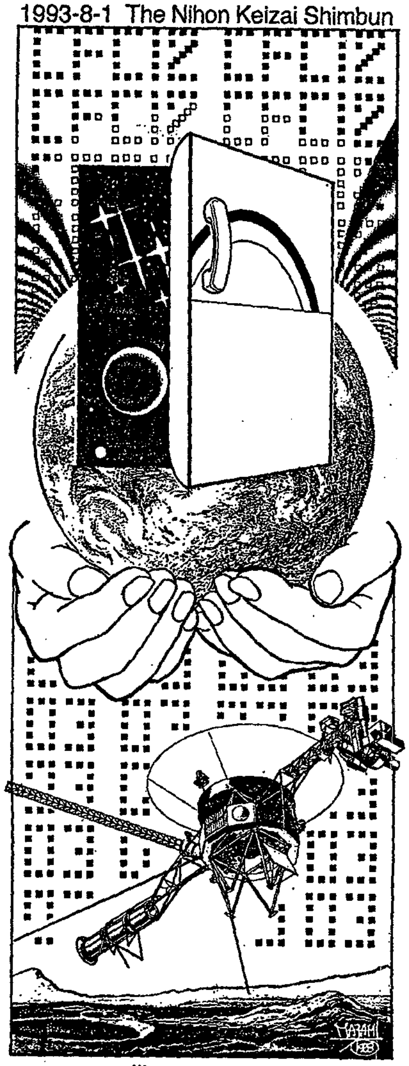
The International Thermoelectric Society

SCT- 93

SHORT COURSE ON THERMOELECTRICS

1993-8-1 The Nihon Keizai Shimbun



Illustrate by Masami Ishii

FOR THE GREEN
21st CENTURY

Pacific Convention Plaza Yokohama
Japan

8th November 1993

Sponsored by the International Thermoelectric Society

Organized by ITS Japan Branch

Editted by: The International Thermoelectric Society

Short Course on Thermoelectrics - 1993 (SCT-93)

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LECTURE # 4

BASIC CONSIDERATIONS IN THE SELECTION OF TE TECHNOLOGY

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1. INTRODUCTION

During the previous two lectures, the basic principles of thermoelectric (TE) technology were explained. These lectures also described how the technology can be applied either to generate electricity or to produce cooling and/or heating. With the materials presented so far, the audience may have gained an understanding of various applications for which TE technology could be considered. These include numerous DC power generators of various capacities and heat sources, refrigerators, air conditioners, and liquid chillers. At the same time, the audience may also wonder why this unique technology has not been applied in a majority of power generators and heating/cooling systems. This lecture is intended to answer these questions.

There are numerous advantages of employing TE technology in a power generating or a heating/cooling system. Also, there are a few drawbacks of employing this technology in a system. The advantages and disadvantages of employing TE technology are described in Section 2.

TE technology is highly suitable for many space, military, industrial, and consumer applications. But, at the same time, it is also true that the technology is not suitable universally for all power generators and cooling/heating devices. There are several factors which one should consider before selecting (or discarding) TE technology for a specific application. These factors are described in Section 3.

To select a technology that is optimum for a specific application, a properly designed evaluation process is required. A simple process was developed to meet this need, which is described in Section 4. Concluding remarks of the lecture are presented in Section 5.

2. ADVANTAGES AND DISADVANTAGES

As stated above, the application of TE technology on various systems has several advantages and disadvantages. These are discussed below in detail.

2.1 Advantages

The principal component of any TE system (either a power generator or a heating/cooling system) is its core. The core contains the TE elements and the heat transfer surfaces. The heat transfer surfaces are fastened to the hot and cold sides of the TE elements. The core, which resembles that of a standard heat exchanger, is a complete solid-state device with no moving parts. Other components in any TE system are fluid pumping components, such as fans and pumps. These are the only moving parts in the system. Because the principal component, the core, is a complete solid-state device, TE systems are highly reliable. During reliability tests, most TE systems have demonstrated a reliability value of 0.99 and above.

Another major advantage of TE systems is that they rarely require maintenance (either preventive or corrective). Once a system is put into service, maintenance is infrequently required on the system. Thus, the cost associated with shutdown for maintenance is considerably reduced.

By properly choosing the pump and fan, the TE system can be designed to operate at an extremely low noise level. This feature may be important for some military, medical, and other domestic applications.

The system generally has a long shelf life. It can be manufactured in quantity and stored for a long period of time. For example, after many years, the system can be removed from storage and put into service without any problems.

The system designed to produce cooling can easily be reversed to provide heating. Similarly, a heating system can be reversed to provide cooling. A single unit also can be designed to provide both cooling and heating. Switching is also very simple because it is done electrically and not mechanically.

Low-capacity TE systems are small in size and are light weight compared to non-TE systems. This advantage is described later in more detail.

2.2 Disadvantages

The main drawback in applying TE technology to today's power generators, air conditioners, and liquid chillers is its low energy efficiency compared to other non-TE units. The ratio between the conversion efficiency of a TE power generator and that of a conventional (heat to shaft power to electrical conversion) generator is only about 0.3 or lower. Similarly, the ratio between the coefficient of performance (COP) of a TE air conditioner and that of a vapor cycle air conditioner is only about 0.8 or lower. The exact value of this ratio is a strong function of the temperature difference between the heat source and sink (ΔT). This aspect is discussed later in more detail.

Another drawback of the TE technology is the initial high cost of producing the TE units. It is not possible to determine the ratio of the initial cost of a TE system to that of a conventional system. This is mainly due to the fact that the initial cost of any production unit is a strong function of the production quantity. Conventional units are produced in large quantities whereas many TE units are still made in small quantities.

3. FACTORS TO BE CONSIDERED IN THE SELECTION PROCESS

Several factors should be considered before selecting TE technology for a particular application. TE technology must be rated against each of these factors. All the ratings must then be added up to determine whether the technology is suitable overall. Some of the major factors against which TE technology should be rated are described below.

3.1 Type of Power

Thermoelectric technology deals with direct current (DC). A TE heating/cooling device requires a source of DC. If the available power source for a specific application is a DC source, then a match exists between the available source and the TE technology. For such heating and cooling applications, the TE technology should be rated somewhat higher. Otherwise, the rating for the TE technology should be lowered. The output of a thermoelectric power generator is a DC power. If the output power required from the generator is a DC power, then again there is a match between the available source and TE technology. For such power-generating applications, the TE technology should be rated somewhat higher.

3.2 Capacity Requirements

Theoretically, one can develop a thermoelectric heating/cooling unit (or a power generator) of any capacity. Both small and large capacity units can be designed and built. However, TE units exhibit a unique size/weight relationship with respect to system capacity. Figure 1 shows a qualitative relationship between the size/weight and the cooling capacity of two air conditioning systems, one being a TE system and the other being a vapor cycle system. In general, the size/weight of TE units are linearly proportional to the cooling capacity. On the other hand, vapor cycle units have a nonlinear relationship as shown in the figure.

It can be seen from Figure 1 that the low-capacity TE units are compact and lightweight compared to vapor cycle units. Based on this factor, one should rate the TE technology favorably if the desired application has a low capacity requirement. Otherwise, the TE technology should be rated low.

3.3 Reliability and Maintainability

For certain special applications (such as medical and military), reliability and maintainability may be more important than other factors, such as energy efficiency. Obviously, TE units are more reliable and easier to maintain than non-TE units. As such, the TE units must be rated very high if these two factors are important for an

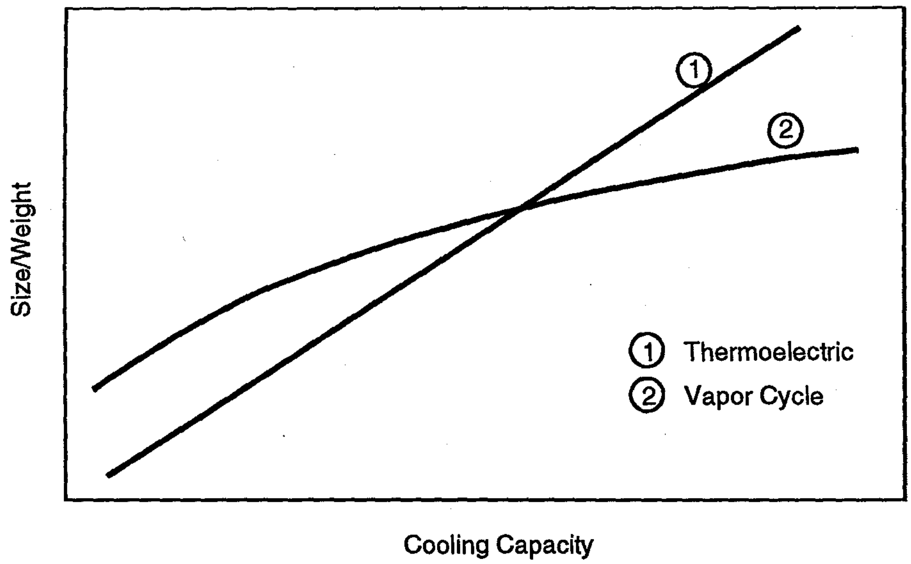

Figure 1. Effect of Cooling Capacity on Size/Weight

application. On the other hand, if these factors are less important compared to others, TE units will be rated low.

Typically, stationary units (of any technology) are more reliable than mobile ones. Therefore, preference is given to non-TE units for stationary applications because reliability is not a major issue. But, for mobile applications, non-TE units are less reliable making TE units more attractive. Therefore, TE units must be rated high for mobile applications from the viewpoint of reliability and maintainability.

3.4 ΔT Requirements

This factor applies primarily to the heating and cooling systems. Figure 2 shows qualitatively the relationship between the COP and the ΔT of two air conditioning systems, one being a TE system and other a vapor cycle system. The TE system COP reaches zero at point A whereas the COP of vapor cycle does not reach zero until point B. The COP of a TE system is always less than that of a vapor cycle system.

The ratio of COPs of the two systems is shown separately in Figure 3. The ratio is high at low ΔT values and the ratio is low at high ΔT values. Of course, at point A, the ratio is zero. It can be seen from Figure 3 that the TE technology is relatively more attractive for low ΔT applications than for high ΔT applications. As such, TE technology should be rated somewhat higher for low ΔT applications; the rating should be lowered for high ΔT applications.

3.5 Quiet Operation

Again for some special applications (such as underwater and medical), quiet operation of the system may be more important than other factors. As previously stated, with a proper selection of fans and pumps, TE units can be designed to operate quietly. Rating for TE units is higher when this is a desired factor; otherwise, the TE units are rated somewhat lower.

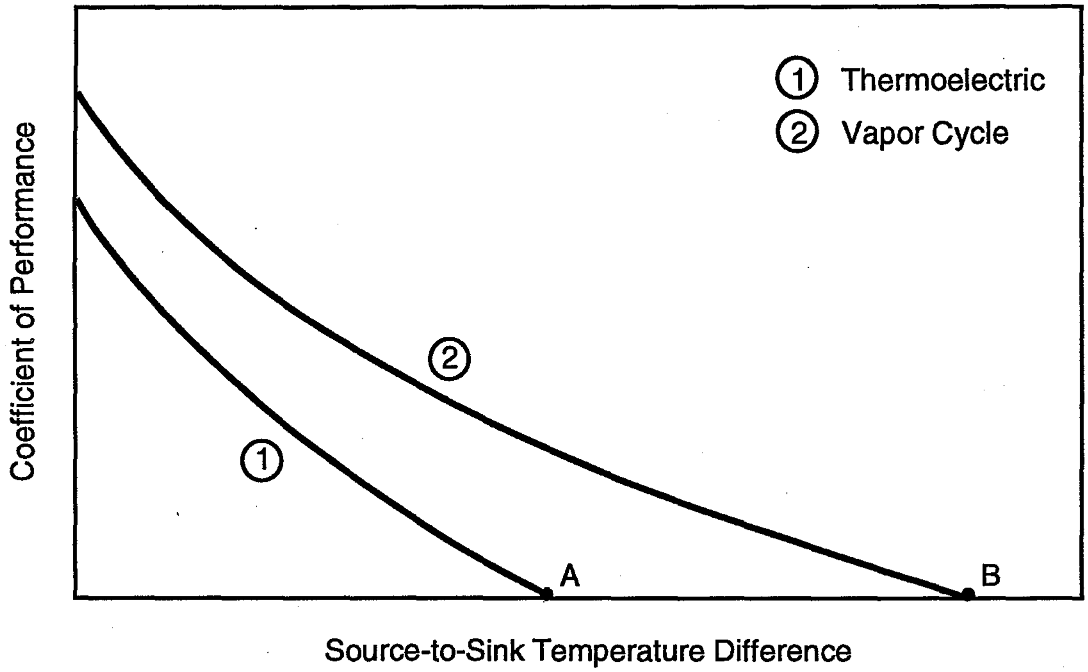

Figure 2. Effect of ΔT on COP

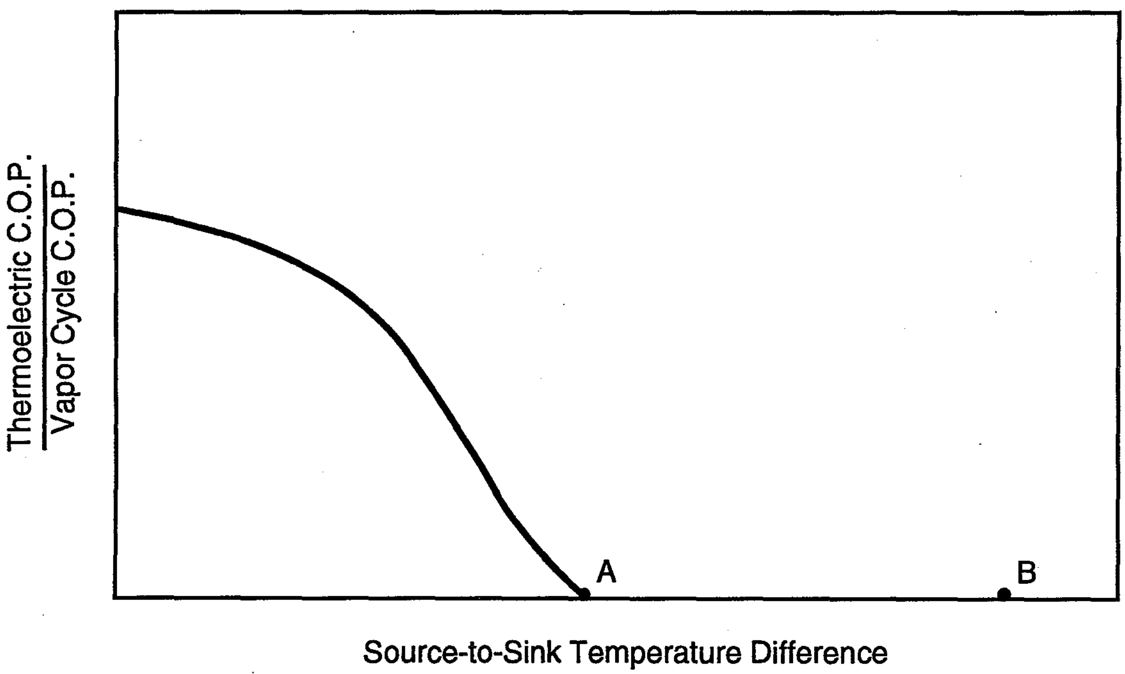

Figure 3. Effect of ΔT on COP Ratio

3.6 Other Factors

Depending on the specific application, one could also consider many other factors, such as initial cost, operating cost, shelf life, need for reversing (from cooling to heating), requirement for operator training, material availability, environmental exposure, etc. TE units must be rated against one or more of these factors as needed.

4. RATING PROCEDURE FOR COMPARISON PURPOSES

A sample procedure for rating two different technologies and selecting the optimum one is illustrated in this section. Assume that an air conditioning system is required for use in military helicopters to cool its occupants. Two technologies—vapor cycle and thermoelectric—need to be evaluated, with the optimum one to be selected.

First of all, various factors that need to be considered for this application should be selected. Let us assume that the following factors are very important for this application: (1) type of power available in the aircraft, (2) cooling capacity, (3) design ΔT between the source and sink, (4) reliability and maintainability, (5) long shelf life, and (6) environmental exposure. We will also assume that other factors (such as initial cost, quiet operation, etc.) are not important and need not be considered in the analysis.

Prepare a table, such as the one shown in Table 1. The first column contains all the factors chosen to be considered for the evaluation. The second column contains the rating against each factor for a TE air conditioner. The third column contains the rating against each factor for a vapor cycle air conditioner.

Table 1 Rating

Factors Considered	TE	Non-TE
Type of Power	60	40
Cooling Capacity	65	35
Design Temperature Difference	30	70
Reliability & Maintainability	70	30
Long Shelf Life	60	40
Environmental Exposure	60	40
Total	345	255

DC power is available in a helicopter and since this aspect is favorable to the TE unit, the rating given was a 60 to 40. The first number '60' corresponds to the TE unit and the second number '40' to the vapor cycle unit.

The cooling capacity required for the air conditioner was about 500 W or only 0.14 ton. This is a very low capacity air conditioner. As such, both size and weight of a TE unit will be significantly lower than a vapor cycle unit. The rating given under this factor was a 65 to 35.

The air conditioner is expected to produce 70°F air in a 120°F environment. This gives a 50°F ΔT between the source and sink. This ΔT is fairly large and therefore the COP of a TE air conditioner will be considerably less than that of a vapor cycle unit. As such, the rating given under this factor is a 30 to 70. Reliability and maintainability factors always provide higher rating to the TE unit. For mobile applications, the ratings are even more favorable. Therefore, a rating of 70 to 30 is assigned under this category.

Normally, military systems are produced in large quantities but are kept in storage until a need arises to use them. Therefore, long shelf life is a major factor for this application. A rating of 60 to 40 is given under this category. The air conditioner is expected to be exposed to some adverse ambient conditions. The unit must survive when exposed to such adverse conditions. In this regard, the TE unit is rated favorably. The rating shown in the table is a 60 to 40.

When the rated values are added together, one can see that the thermoelectric system leads the competing vapor cycle system by 345 to 255. Thus, one can objectively conclude that the TE units are the right choice for this application.

In the above analysis, each factor considered has been given equal importance and therefore weighted equally. In some cases, one might select not only the important factors to be considered but also the level of importance by assigning different weight coefficients to each of these factors.

A similar evaluation can be conducted for any desired application. For instance, we did a similar analysis for automobile air conditioners. The analysis indicated that the vapor cycle units are the preferred choice for this application.

5. CONCLUDING REMARKS

Thermoelectrics is a unique technology. It has certain characteristics that no other technology has. Therefore, it is a technology that will find many applications in the future. At the same time, the technology has some serious limitations as well. For someone who is exploring the possibility of using TE technology for his application, a thorough understanding of the technology and of the evaluation process is necessary. With the procedures outlined above, one can make a more objective judgment in the selection process.